Technical Study on IOWN for Mobile Networks

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Abstract

The IOWN for Mobile Network Task Force has been investigating technical topics related to mobile and transport networks in the Innovative Optical and Wireless Network (IOWN), including the study of the key requirements for transport networks in the transition from the current 5th-generation mobile communications system (5G) to 6G, analysis of the gaps in technology hindering actualization of the uses cases aimed at by the IOWN Global Forum and proposal of solutions to them, and exploration of a future transport network architecture that leverages the All-Photonics Network and data-centric infrastructure. This article introduces the activities of this task force.

Keywords: Technical Outlook for Mobile Networks Using IOWN Technology, PoC Reference, IMN

1. Technical Outlook for Mobile Networks Using IOWN Technology

The IOWN for Mobile Network Task Force (IMN-TF) has been studying, proposing and discussing, together with global vendors and carriers, use cases and technologies required for mobile and transport networks that use IOWN Global Forum (IOWN GF) infrastructures. The IMN-TF released "Technical Outlook for Mobile Networks Using IOWN Technology" [1] in January 2022 and "Technical Outlook for Mobile Networks Using IOWN Technology - Advanced Transport Network Technologies for Mobile Network" [2] in April 2023. This article focuses on the topics that have been discussed in the IMN-TF activities to date.

Many advanced use cases for the 5th-generation mobile communications system (5G), including video-centric applications and latency-sensitive cases, such as area management, telesurgery, augmented reality/virtual reality, and industrial automation, demand huge end-to-end bandwidth capacity, high reliability and availability, and extremely low latency on mobile networks. Among the various technologies that can be used to provide transport networks for mobile cell sites, fiber is the best solution for fixed network sites because of its high capacity and widespread deployment. Therefore, the IMN-TF is proposing a method for implementation using fiber-based optical transport networks for mobile networks that use the data-centric infrastructure (DCI) and Open All-Photonic Network (Open APN) architectures.

5G can achieve high data rates using a wide bandwidth available in millimeter wave frequency bands but requires a high-density installation of cell sites to cover a given area. Mobile-network infrastructures are evolving toward cloud-native network function virtualization, which opens up a variety of transport network options and configurations. We are studying such options and configurations from both technical and economic perspectives, including whether they are in line with technical trends, will improve service deployment and provisioning agility, and will reduce operating costs.

New services and applications enabled by 5G will use enhanced mobile broadband, ultra-reliable low latency communication, massive machine-type communication, and fixed wireless access technologies. Such new services and applications generate larger amounts of data and require latency to be extremely low. As the volume of data in mobile networks increases, the entire transport network, from the backhaul to the datacenter, is required to have high

Table 1. Target fronthaul bandwidth and delay requirements of various RAN split options.

KPI	5G (2020)	6G (2030) (Projected)
E2E		
Peak data rate	< 10 Gbps	< 100 Gbps–1 Tbps
User plane latency (ms)	1	0.1
Transport: Lower Layer Split (Option 7)		
Bandwidth	< 25–50 Gbps	< 250 Gbps–5 Tbps
Frame delay (one-way)	0–160 µs Fiber delay: 0–150 µs (0–30 km) Packet delay variation (PDV): 0–10 µs (0–2 switches)	0–larger than 160 µs Fiber delay: 0–larger than 150 µs (0–larger than 30 km) PDV: 0–less than 10 µs
Transport: Higher Layer Split (Option 2)		
Bandwidth	< 10 Gbps	< 100 Gbps–1 Tbps
Frame delay (one-way)	Up to ms order (up to 100 km order)	Up to ms order (up to 100 km order)

E2E: end to end
KPI: key performance indicator

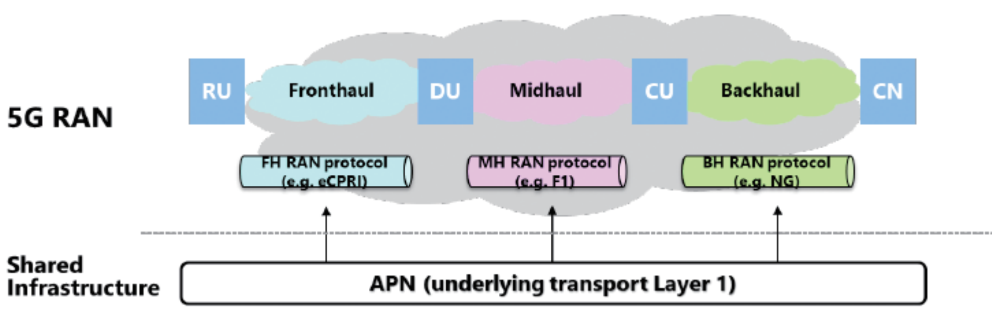

Fig. 1. RAN and the APN.

capacity. People are increasingly using time-sensitive applications, which demand ultra-low latency on the order of milliseconds. Among the technical reports released by the 3rd Generation Partnership Project (3GPP), 3GPP TR 38.801 [3], 3GPP TR 38.806 [4], and 3GPP TR 38.816 [5] specify eight possible radio access network (RAN) functional split options. The most stringent requirements considered by mobile carriers are listed in **Table 1**. The IMN-TF will conduct a proof of concept (PoC) on the feasibility of building a transport-network solution that can meet these stringent requirements (**Fig. 1**).

Considering that IOWN mobile networks use the All-Photonics Network (APN) and DCI technologies, the task force is discussing scenarios for RAN deployment on the APN/DCI, high availability and fault tolerance enabled by the DCI and APN, and use cases involving elastic load balancing, which reduces power consumption by flexibly operating base stations in response to daytime and nighttime variations in mobile traffic.

1.1 RAN deployment scenarios on APN/DCI

In studying scenarios for RAN deployment on the APN/DCI, it is necessary to consider the connectivity and performance of the transport layer. The definition of a transport-connection service typically includes topology, a user network interface, traffic/bandwidth profiles/characteristics, protocols, and a set of their service attributes. When setting up connections to RAN functions, it is important to support the characteristics of the RAN domain, such as connections using the standardized enhanced Common Public Radio Interface of the Fronthaul (FH) RAN protocol.

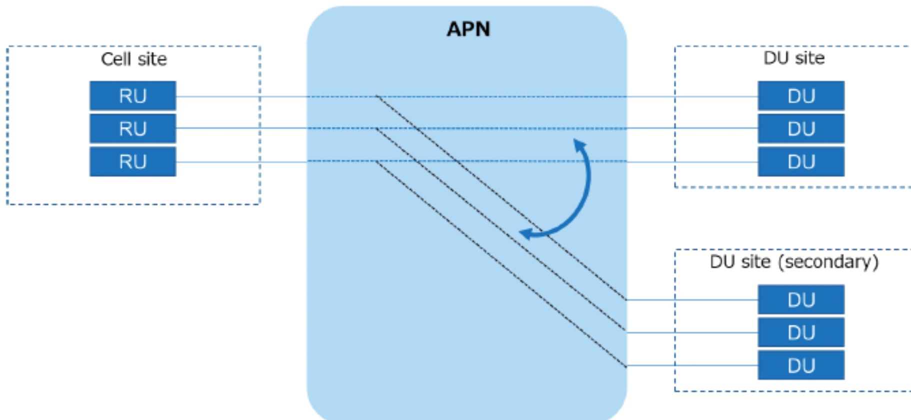

Fig. 2. Dynamic path switching to achieve high availability and elastic load balancing.

There are two methods for connecting each RAN function to the APN: one that directly terminates a wavelength path with an optical transceiver and another that uses a bridging function such as a flexible bridge service.

Passive optical network (PON) technology can be used to directly connect the radio unit (RU) side to the APN. For example, time division multiplexing (TDM)-PON can be used. However, when using TDM-PON, it is necessary to limit the distance between an RU and distributed unit (DU) to 10 km or less to compensate for any packet delay that exceeds the packet delay variation (PDV) requirement (10 microseconds). An advantage of using a flexible bridge service is that multiple types of services can be defined to support multiple quality of service levels (delay, jitter, etc.) depending on the given use case. The task force is discussing various APN-mediated solutions, including a flexible bridge service, and developing a PoC Reference [6] for a demonstration model for Mobile FH over APN that satisfies both stringent mobile fronthaul requirements and a wide variety of base-station installation configurations.

1.2 High availability and elastic load balancing

By combining the APN, DCI and a subsystem, namely, a RAN intelligent controller, it becomes possible for the FH network to flexibly switch DUs within a DCI resource pool. A virtualized DU (vDU) is a virtual node that runs on a network functions virtualization infrastructure (NFVI) and can be freely reconfigured on multiple NFVIs installed at different geographic locations. We believe that we can leverage this feature to reduce power consumption. The associations between physical servers, DUs, and RUs in an FH network may change as a result of external triggers such as the failure state of the components involved, load balancing requirements, and energy saving requirements. High availability of RAN systems can be achieved by changing the physical associations between RUs and DUs using the APN-wavelength path-switching function when triggers such as the following occur: traffic fluctuation or detection of a problem such as a failure or service degradation detected by the network. For example, all user devices (user equipment: UE) connected to an RU reconnect to a new DU that has been reconfigured on a physically different server, or some of the RUs connected to a DU reconnect to a physically different DU taking the balancing of resources into account. We are studying an elastic load-balancing function to improve flexibility and resource-utilization efficiency in these FH networks. This function is expected to improve the availability and power efficiency of RAN systems. For example, by shutting down unused DCI resources (vDUs), thus reducing their power consumption, we can improve the power efficiency of RAN systems (**Fig. 2**).

1.3 Enhanced CTI

With a view to providing end-to-end low-latency and low-jitter services using IOWN technology, the IMN-TF is also studying an extended cooperative transport interface (eCTI) between a mobile network and the APN.

When using an optical access system as a transport network for a mobile system, it is necessary to reduce the latency of the optical access system because the

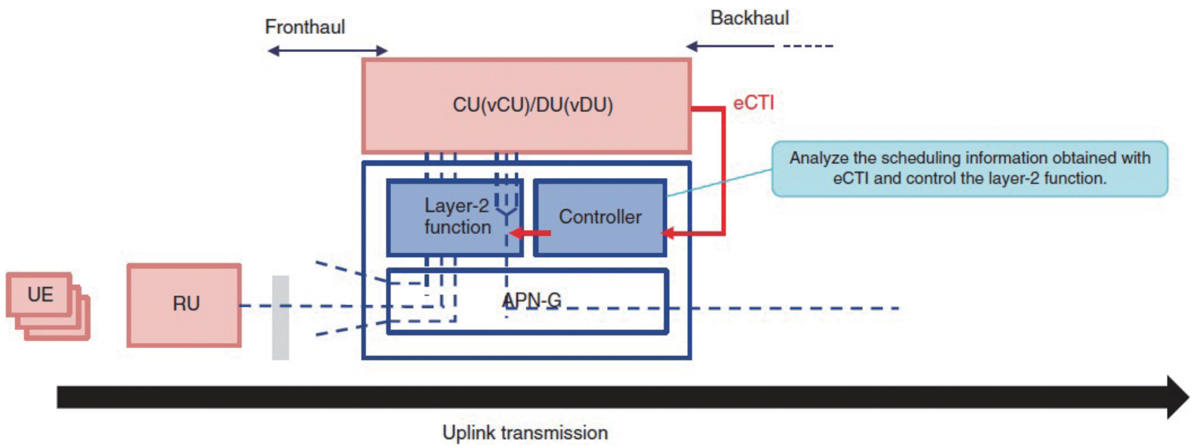

Fig. 3. eCTI overview.

allowable latency for a mobile system is very short. Therefore, cooperative dynamic bandwidth allocation (CO-DBA), a function to reduce latency by determining the communication timing of the optical access system in cooperation with the mobile system, was specified. The Open Radio Access Network (O-RAN) Working Group (WG) 4 has specified a CTI, which is the interface between the mobile system and optical access system for exchanging the information required for operating CO-DBA. Since the current CTI specification cannot be applied to short transmission time interval and mobile midhaul (MH)/backhaul (BH) that provide services demanding low latency in a mobile network, it is necessary to extend the CTI specification as an eCTI in the IOWN GF architecture. We are studying a latency-control method with which an orchestrator coordinating the mobile network and APN operations collects mobile information, such as the aggregate traffic load, and transfers the data to the APN controller. In implementing high-precision remote control and automatic operation of robots and other devices, stable control is difficult if the fluctuations (jitter) of packet arrival time are large. Therefore, it is necessary to keep jitter, which has not been specified as a performance requirement in conventional networks, within a certain time frame.

To suppress delay fluctuations, we are discussing a method for controlling the devices that make up the mobile system and transport network on the basis of information about transmission timing and the volume of transmitted data in the wireless section (**Fig. 3**).

2. PoC Reference

The IMN-TF recognizes that, to support the use cases envisioned by IOWN GF, it is necessary to satisfy the very stringent O-RAN FH requirements and that the Open APN is a promising solution for meeting these requirements. It is therefore necessary to demonstrate the feasibility of implementing mobile FH to which the APN is applied. While various technologies and architectures have been considered for FH solutions, the task force considers that one of its missions is to demonstrate the value of applying the APN to FH, thereby having the APN recognized widely as a major FH solution.

The purpose of this PoC is to demonstrate, to mobile network operators and other operators who wish to offer FH as a service, the benefits of applying the Open APN as an FH solution and the feasibility of O-RAN key performance indicators (KPIs) and present the demonstration test results. We expect that the recognition of Mobile FH on APN as a viable and promising solution will encourage mobile network operators worldwide to adopt this solution, which in turn will lead to further advancement of IOWN GF-related technologies.

There are two aspects that we want to demonstrate in this PoC. The first is a benchmark test to demonstrate that the energy efficiency of the APN is higher than that of other alternative solutions. An example of its benefits is that the operating cost can be reduced because the APN eliminates the conversion from electricity to light and vice versa. The second is to demonstrate the feasibility of implementing network functions that can support high-availability services

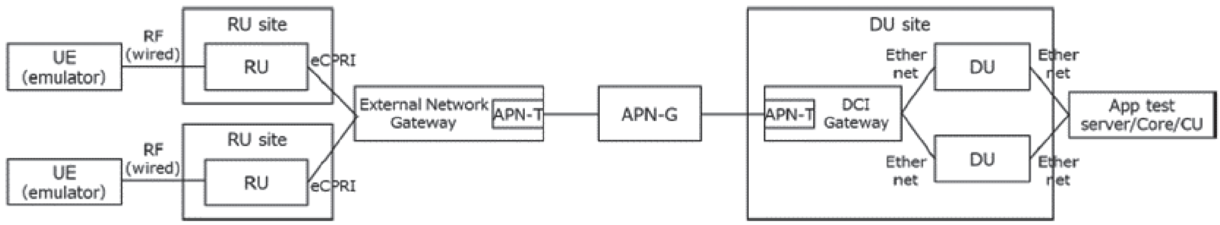

Fig. 4. Network configuration for PoC Step 1.

and elastic load balancing. Elastic load balancing is a term used in the definition of a use case in which connections of RUs to a set of vDUs can be actively and dynamically switched on the basis of actual load on the DUs. Although directly connecting RUs to vDUs using dedicated dark fibers without multiplexing is more efficient than using the APN, dedicated dark fibers do not give mobile network operators the flexibility to dynamically allocate computing and other necessary resources to DUs in response to traffic fluctuations. The APN, however, allows dynamic switching of wavelength paths, which enables mobile network operators to flexibly use computing resources at the destination in response to the current traffic volume and other factors. We believe that the APN will enable mobile network operators to optimize their DU computing resources, thus reducing both operating costs, including power costs, and base-station costs.

In this PoC, we plan to prove the feasibility of these two possibilities separately in two steps.

In Step 1, we will evaluate the feasibility of Mobile FH over APN. It will demonstrate that the very stringent O-RAN mobile FH requirements can be met. These requirements are specified in an O-RAN specification (O-RAN Fronthaul Interoperability Test Specification (IOT)) and in the technical requirements in IMN documents.

In Step 2, we will evaluate the energy efficiency of elastic load balancing. We already compared the energy efficiency of a model in which packets are multiplexed using layer 2/layer 3 (L2/L3) switches over dark fiber in normal operation mode with that of a model in which elastic load balancing is applied, and demonstrated the extent to which the latter reduced power consumption compared with the former. We will evaluate the impact of using the APN on services and operations. Specifically, we will verify the extent of end-to-end throughput degradation, the total time needed to switch vDU hosts, and changes in end-to-end throughput during switching of DU hosts to determine whether there are any service-continuity issues or other technical issues.

In Step 1, we plan to show that the O-RAN KPI is satisfied by collecting the latency and throughput data of the synchronization plane, control plane, and user plane using virtualized RAN (vRAN) devices and APN devices in the following network configuration.

Mobile FH between RUs and DUs is located at a certain distance apart and vDUs are concentrated at the same site. The minimum configuration is defined as follows. There are multiple RU sites in one cell site. Since signals from these RUs are to be multiplexed into one fiber on the APN, at least two RU sites are needed* (**Fig. 4**).

In Step 2, we plan to confirm the feasibility of the concept of elastic load balancing in the following network configuration. The environment in Step 1 will be extended so that, in addition to collecting data as in Step 1, the effectiveness and usefulness of the concept can be evaluated. In the extended environment, multiple vDUs will be deployed to allow switching from distributed processing on multiple hosts to centralized processing on a single host (**Fig. 5**).

The evaluation of two dynamic path-switching methods for wavelength switching on the APN is defined as follows.

Method 1 is based on optical switching. When the traffic aggregated for each vDU varies, this method switches the optical path between the extra network gateway and DCI gateway so that the APN gateway

* Bandwidth per RU: 10G, 25G, or 50G; distance between RU and DU: 2 patterns, 10–30 km.

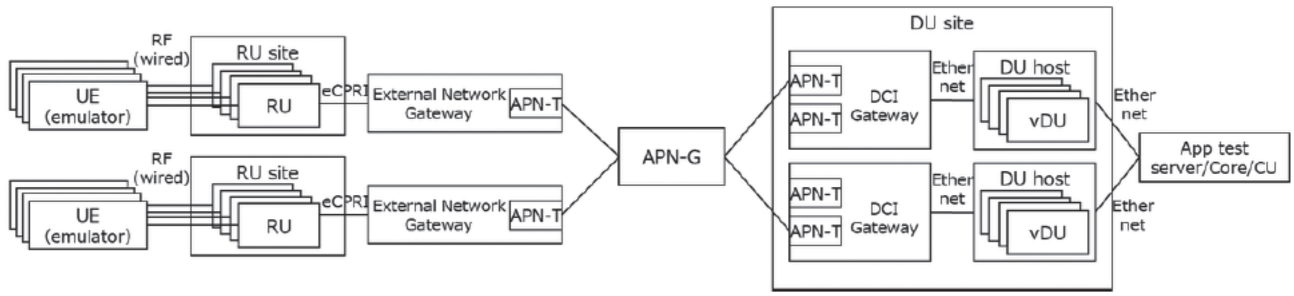

Fig. 5. Network configuration for Step 2.

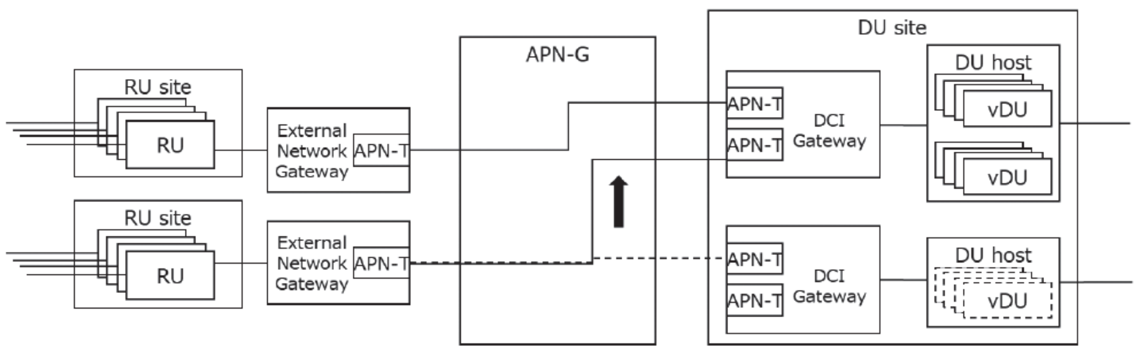

Fig. 6. Method based on optical switching.

(APN-G) will be reconfigured to optimize the number of vDUs used. More specifically, suppose that both RU sites and DU hosts are respectively connected. When the workload on the DU side decreases, this method switches the optical path that has been connected to the lower DU host to the upper DU host so that the upper DU host will handle the entire workload (**Fig. 6**).

Method 2 is based on packet switching. When the traffic varies, the DCI gateway switches the L2/L3 path between the DCI gateway and a DU host so that the vDUs will be reconfigured. More specifically, suppose that both RU sites and DU hosts are respectively connected. When the workload on the DU side decreases, this method switches the L2/L3 path to the upper DU host so that the upper DU host will handle the entire workload (**Fig. 7**).

In Step 2, the measurement of operational data and service level data is defined, including energy consumption, switchover time, and service-interruption time of the Open APN and external networks between the RU sites and DU hosts in addition to latency and throughput included in the measurements in Step 1.

3. Status of PoC implementation

IMN-TF member companies are holding discussions in preparation for both Steps 1 and 2, which are scheduled to be conducted up to FY2023. Member companies are stepping up efforts for Step 1, which includes five PoC projects that are either in process or in a preparatory stage. IMP-TF has received and discussed various proposals for detailed network configurations of Mobile FH over APN from different companies and finally agreed on two models based on the APN technology in accordance with the PoC Reference. The task force members continue to discuss whether the proposed solutions are promising and will clarify possible use cases and benefits. Subsequent PoC projects and evaluation will then be carried out.

For Step 2, the task force aims to discuss detailed use cases, operating-condition specifications, KPIs, and data to be collected and revise the PoC Reference toward the second half of FY2023.

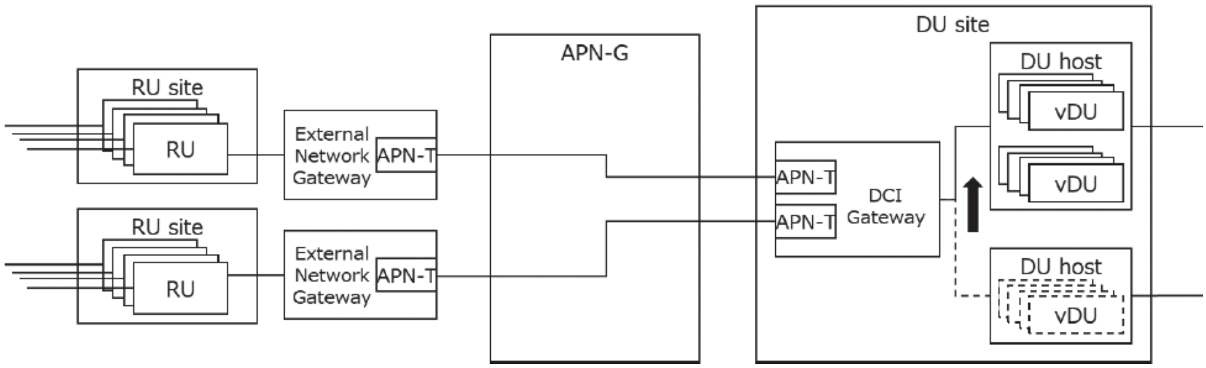

Fig. 7. Method based on packet switching.

4. NTT Group's activities in IMN-TF

NTT Group's activities in the IMN-TF are twofold.

First, NTT laboratories are proposing to use the results of their research on coordinated optical wireless control technology [7]. Mobile systems, which constitute wireless sections, use a wired network for the transport network that establishes connections between base-station devices and connections with the core network. However, mobile systems and the transport network have conventionally been designed, constructed, and operated independently of each other. Therefore, they cannot operate as a single unit capable of dynamically changing the operation of the transport network in accordance with the state of the mobile systems. To provide services that require low latency in a mobile network, it is necessary to control and reduce latency through optical paths and DCI gateways on the basis of mobile information provided by network devices, such as DUs. The function for reducing latency is specified as CTI by O-RAN WG 4. NTT laboratories have extended the CTI specification to define an eCTI for the IOWN GF architecture and studied a method with which the APN controller reduces both end-to-end latency and jitter by obtaining mobile information from CUs/DUs through the eCTI. On the basis of this study, NTT laboratories are leading discussions for producing a proposal on a latency/jitter-reduction method and for demonstrating its feasibility.

Second, NTT DOCOMO has been operating and supporting the IMN-TF as a co-coordinator since April 2022. On the strength of its experience in the commercial deployment of Open RAN and in the promotion of vRAN through OREX, and through its communication with other task force members, NTT DOCOMO is leading efforts to ensure smooth progress of task force activities. Examples are formulating activity plans for the IMN-TF, setting goals and targets for each topic, proposing agendas and summarizing discussions held in member meetings, and inputting the trends of international standardization bodies such as 3GPP and O-RAN Alliance. The IMN-TF will continue to work on solving problems in the mobile domain, including the actualization of elastic load balancing.

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